BBC RD 1981/4

RESEARCH DEPARTMENT REPORT

V.H.F. RADIO-DATA: experimental BBC transmissions

S.R.ELY, B.Eng., Ph.D.

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION June 1981

Published by

BBC Research & Development

Kingswood Warren

Tadworth

Surrey

KT20 6NP

England

http://www.bbc.co.uk/rd

BBC RD 1981/4
UDC 621.396.2.
029.62

V.H.F. RADIO-DATA: EXPERIMENTAL BBC TRANSMISSIONS

S. R. Ely, B.Eng., Ph.D.

Summary

This report describes in detail a new system for transmitting data signals from v.h.f. radio-broadcast transmitters along with the normal sound-programme signal. These data signals are primarily intended to aid radio listeners in tuning their receivers to a desired station or programme. They are imperceptible to listeners with existing receivers but suitably equipped future domestic radio-receivers could decode the messages for display or control purposes.

The new system described here has been developed by the BBC and currently (April 1981) it is experimentally on-air from three v.h.f. radio-broadcast transmitters in the London area. The data signals are conveyed on a 57 kHz subcarrier which is suppressed-carrier amplitude-modulated. A data rate of about 1187.5 bit/s is obtained and biphase coding reduces the sideband-power close to 57 kHz.

The principal feature of the data format described in this provisional specification is a modified cyclic block-code which reliably detects nearly all possible error patterns and provides block synchronisation information without the need for a separate header code for this purpose.

In the proposed system each transmitted block is a self-contained packet containing an address and each block can be decoded independently of the others adjacent to it. This addressing system gives the flexibility to service a wide range of needs and to evolve gradually as new applications become apparent.

The present on-air experimental system broadcasts simple fixed messages which are thought to be representative of those which would be broadcast in a final operational system.

Issued under the authority of

Head of Research Department

Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION

(EL-159)

V.H.F. RADIO-DATA: EXPERIMENTAL BBC TRANSMISSIONS

Section	Title	Page

V.H.F. RADIO-DATA: EXPERIMENTAL BBC TRANSMISSIONS

S.R. Ely, B.Eng., Ph.D.

1. INTRODUCTION

For some years the BBC[1,2] and other European broadcasters[3,4] have been investigating systems for broadcasting radio-data signals from v.h.f. radio-broadcast transmitters.* These data signals will be primarily intended to aid radio listeners in tuning their receivers to a desired station or programme.

Although no firm specification for radio-data has yet been agreed by European Broadcasters, some general principles have achieved widespread acceptance within the EBU. It is therefore considered helpful to provide this description of the proposed BBC radio-data system for those manufacturers who are contemplating the development of domestic radio-data receivers. If a service is established, it will hopefully have much in common with the system described in this document.

Experiments have so far shown that the preferred method for broadcasting these data signals uses a subcarrier and that the preferred frequency for this subcarrier is in the region of 57 kHz.

CCIR Document 10/30 (1970-74) allows for such a supplementary 57 kHz subcarrier to be added to pilot-tone stereophonic broadcasts or to monophonic broadcasts and indicates that the deviation of the main carrier by the subcarrier may be up to ± 7.5 kHz.

The BBC and Televerket of Sweden have developed a 57 kHz radio-data system in which the subcarrier is phase-locked to the third harmonic of the 19 kHz pilot-tone and is modulated by biphase coded data at about 1187.5 bit/s. The peak-deviation of the main carrier due to the 57 kHz subcarrier is about ± 2.25 kHz.

Extensive laboratory and over-air tests have indicated that the compatibility with programme (i.e. interference, if any, suffered by existing receivers when the radio-data signals are added) of this system is good, with few receivers suffering any impairment (in the form of audible whistles or increased crosstalk between the stereophonic channels.) Similarly, data reception under adverse receiving conditions (due to low field-strength or multipath propagation) has been found to be adequate.

It is not the intention of the BBC to radiate ARI** signals, but it is desirable that any proposed radio-data system should be compatible with the ARI system (which is used to provide a motoring information service in some other European countries (see CCIR Document 10/198 1970/74)). The 57 kHz radio-data system described here has been found to have good compatibility with the ARI system, even when both systems are broadcast simultaneously from the same transmitter. This is made possible by the fact that the ARI system has all its signal-power at and close to 57 kHz and uses narrowband decoder circuits in its receivers, whereas this 57 kHz radio-data system (because of the biphase coding of the data) has very little signal-power

* *The BBC have also developed a system for broadcasting data signals from l.f. transmitters.*

** *Autofahrer Rundfunk Information.*

close to 57 kHz. It is, however, advisable to take ARI into account when designing radio-data decoders so that satisfactory data reception is ensured in those countries which choose to broadcast both radio-data and ARI signals simultaneously.

This report describes the parameters of the radio-data system which in April 1981 began to be radiated experimentally from three BBC v.h.f. transmitters in the London area: Radio 2 (89.1 MHz), Radio 4 (93.5 MHz) and Radio London (94.9 MHz). The report concentrates mainly on the details of the data channel, i.e. the subcarrier frequency, modulation method, data rate, spectrum shaping, coding, error protection and block synchronisation of the experimental system.* This information should enable interested receiver manufacturers to receive and decode the data signals off-air.

The message content of the transmitted data signals is considered in less detail since there are more uncertainties about these aspects at present. However, in order to provide manufacturers with a meaningful message for decoding, about 35% of the available data channel capacity is being used to transmit the most likely types of message, including the network name (e.g. BBC R4)(in ASCII code) for display. The remaining 65% of the available capacity is at present packed with dummy data from a pseudo-random binary sequence generator.

The message format is so designed that it will be possible gradually to replace the dummy data with real messages as and when the details of information and applications are decided upon.

2. DATA CHANNEL

The data signals are carried on a subcarrier which is added to the stereo multiplex signal (or monophonic signal as appropriate) at the input to the v.h.f./f.m. transmitter. Block diagrams of the data source equipment at the transmitter and a typical receiver arrangement are shown in Figs. 1 and 2, respectively.

2.1 Subcarrier frequency.

During stereo broadcasts the subcarrier frequency will be phase-locked to the third harmonic of the 19 kHz pilot-tone. Since the tolerance on the frequency of the 19 kHz pilot-tone is ± 2 Hz (see CCIR Recommendation 450), the tolerance on the frequency of the subcarrier during stereo broadcasts is ± 6 Hz.

The tolerance on the phase-angle between the third-harmonic of the 19 kHz pilot-tone and that of the radio-data subcarrier is not specified but, in those countries** where ARI signals are transmitted simultaneously, the phase-angle between the ARI subcarrier (which is nominally in phase with the third-harmonic of the 19 kHz pilot-tone) and the suppressed-carrier of the radio-data should not exceed ± 10° (as measured at the modulation input to the f.m. transmitter.)

* *The experimental radio-data system at present broadcast by Televerket in Sweden differs from the BBC system described here in some of these aspects, notably in block-length, error-protection and block- synchronisation strategy.*

** *Not the U.K.*

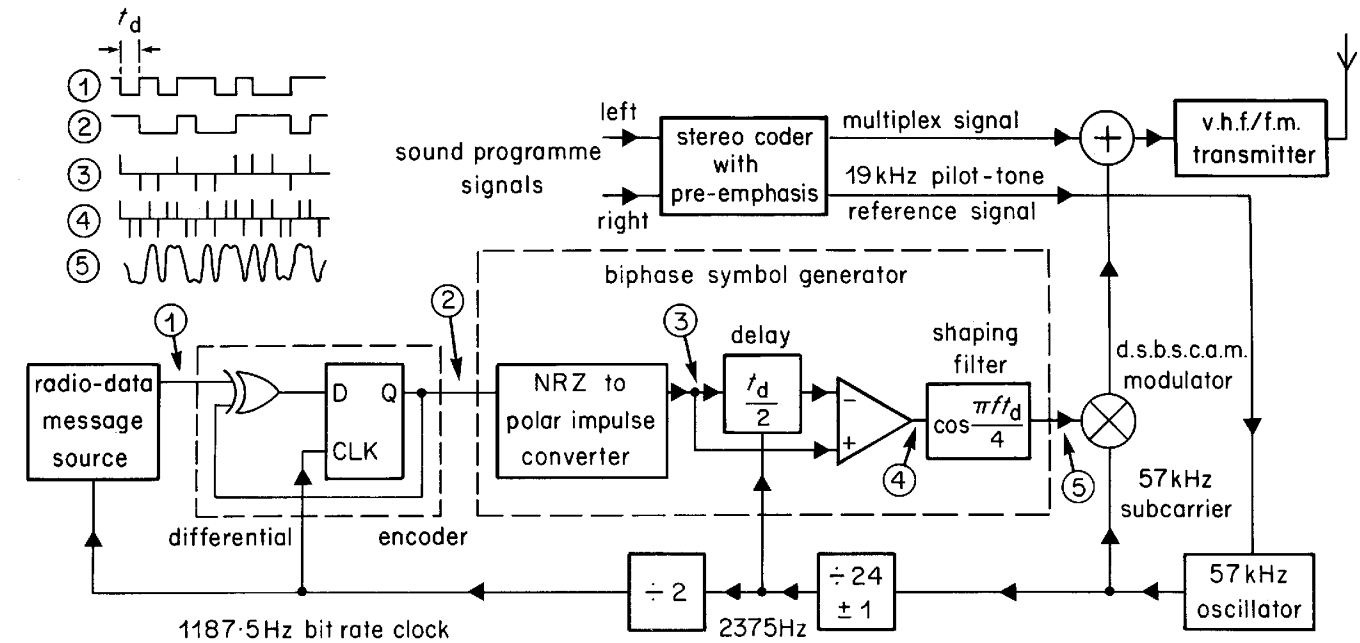


Fig 1. Block diagram of radio-data equipment at the transmitter.

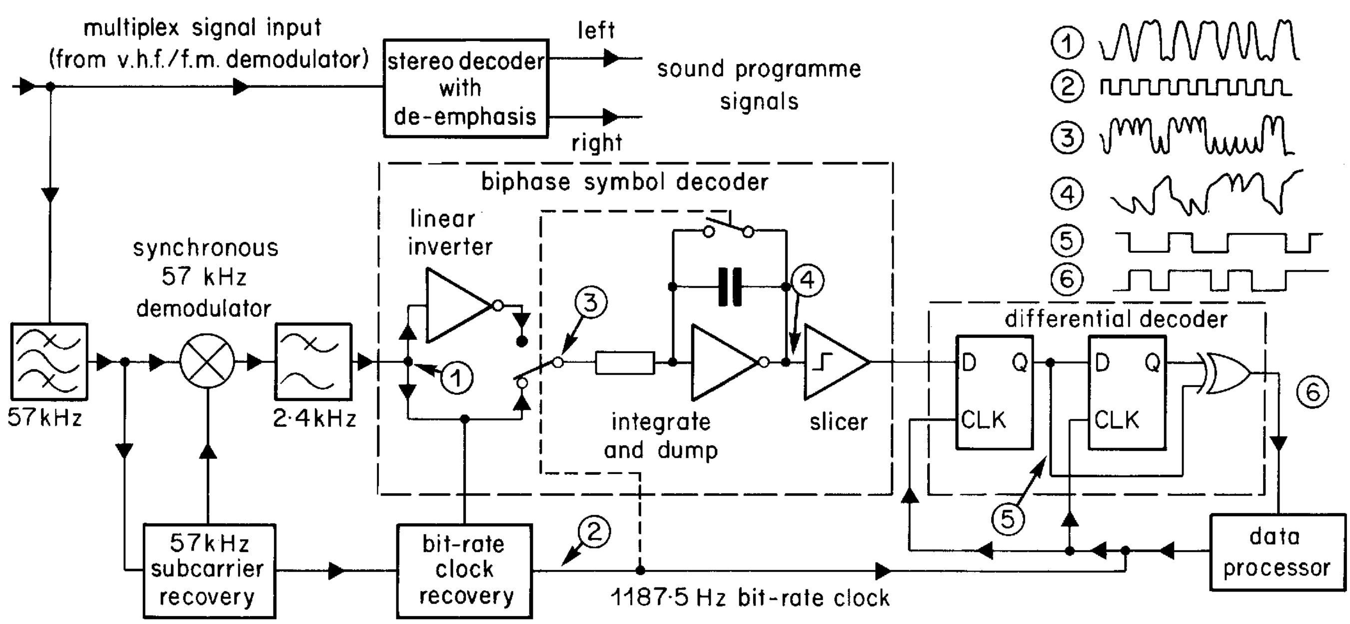


Fig 2 Block diagram of a typical radio-data receiver/decoder

During monophonic broadcasts the frequency of the subcarrier will be 57 kHz ± 6 Hz.

It is clearly essential, in view of the need for the radio-data decoder to work correctly during monophonic broadcasts (when the pilot-tone is absent), that the transmitted pilot-tone is not used as a reference signal when demodulating or decoding the data.

2.2 Method of Modulation.

The subcarrier is double-sideband suppressed-carrier amplitude-modulated (d.s.b.s.c. a.m.) by the shaped and biphase-coded data signal (see Section 2.6). This method of modulation may alternatively be thought of as a form of two-phase phase-shift-keying (p.s.k.) with a phase-deviation of ± 90°.

2.3 Subcarrier Level.

The nominal peak deviation of the main f.m. carrier due to the unmodulated subcarrier is ± (2.25 kHz ± 1.25 kHz*). Thus the level of each sideband of the subcarrier, corresponds to half the nominal peak deviation level of ± 2.25 kHz, i.e. ± (1.125 kHz ± 0.625 kHz) for an 'all-zeroes' message data stream (i.e. a continuous bit-rate sine-wave after biphase encoding).

The maximum permitted peak-deviation due to the composite multiplex signal is ± 75 kHz.

2.4. Data-Rate.

The basic data-rate of the system (see Fig.1) is nominally 1187.5 bit/s. This clock frequency is derived at the transmitter by dividing the transmitted subcarrier frequency by 48.

However, to facilitate phasing of the transmitted code words this division ratio may occasionally be momentarily altered to 50 or 46 - in such a way as to insert or delete one 57 kHz cycle in each half of the biphase symbol corresponding to a data-bit (see Section 2.6.2). Such lengthening or shortening will not occur more than once in every 114 data bits.

2.5 Differential Coding.

In common with many p.s.k. data transmission systems, in the suppressed carrier system proposed here there is no simple way of obtaining an absolute phase reference for regeneration of the subcarrier in the receiver/ demodulator.** The subcarrier reference which can be regenerated from the received modulated subcarrier usually has a 180° phase ambiguity and consequently the demodulated data signal may, equiprobably, be inverted or not. To overcome this ambiguity the source data at the transmitter is differentially encoded according to the following rules:

* *This is the present adjustment tolerance in the experimental system, but headroom should be allowed in the decoder/demodulator for the full ± 7.5 kHz permitted by the CCIR draft provisions for supplementary subcarriers.*

** *An absolute phase reference for the subcarrier can in principal be obtained from the received signal by using the fact that the bit-rate is an exact integral divisor of the subcarrier frequency and extracting the phase information at the data-transitions.*

Previous Output (at time t_{i-1})	New Input (at time t_i)	New Output (at time t_i)
0	0	0
0	1	1
1	0	1
1	1	0

(where t_i is some arbitrary time and t_{i-1} is the time one message-data clock-period earlier (and where the message-data clock-rate = 1187.5 Hz)). Thus, when the input data level is 0, the output remains unchanged from the previous output bit and when an input 1 occurs, the new output bit is the complement of the previous output bit.

In the receiver/decoder, the data may be decoded by the inverse process viz:-

Previous Input (at time t_i-1)	New Input (at time t_i)	New Output (at time t_i)
0	0	0
0	1	1
1	0	1
1	1	0

Thus the data is correctly decoded whether or not the demodulated data signal is inverted. The penalty for this is, of course, an increase in the error rate, since an error will occur if either the present or previous received data bit is wrong.

2.6 Data-Channel Spectrum-Shaping

2.6.1 General Considerations

As in most data transmission systems it is essential to shape the raw binary data waveform before transmission to limit the bandwidth occupied by the transmitted data signal. In the data receiver the recovered data signal should pass through a matching filter which maximises the received signal-to-noise ratio at its output. In addition, the overall spectrum-shaping provided by the transmitter and receiver filters must satisfy Nyquist's criteria for zero intersymbol interference.[5]

A further requirement in this system is to minimise the power of the data signal at and close to the 57 kHz subcarrier. This is necessary because the data signal power close to 57 kHz can cause data-modulated cross-talk in

some stereo decoders. In addition, it is desirable to achieve compatibility with the ARI motoring information system which is used in some other European countries (in the ARI system all the signal power is found at and very close to 57 kHz).

2.6.2 Biphase Symbol Generation

The requirement of small signal power close to the subcarrier is met by coding each source data bit as a biphase symbol. The process of generation of the shaped biphase symbols is shown schematically in Fig.1. In concept, each source bit gives rise to an odd impulse-pair, e(t), such that a logic 0 at source gives:

$$e(t) = \delta(t) - \delta(t+t_d/2) \qquad \text{...............(1)}$$

and a logic 1 at source gives:

$$e(t) = -\delta(t) + \delta(t+t_d/2) \qquad \text{...............(2)}$$

These impulse pairs are then shaped by a square-root of 100% cosine roll-off filter*, $H_T(f)$ to give the required band-limited spectrum where:

$$H_T(f) = \begin{cases} \cos\left(\dfrac{\pi f t_d}{4}\right) & ; \quad 0 \leqslant f \leqslant 2/t_d \\ 0 & ; \quad f > 2/t_d \end{cases} \qquad \text{...............(3)}$$

and here $t_d = \dfrac{1}{1187.5}$ Hz.

It may readily be deduced that the resulting shaped symbols possess little very low-frequency energy, as required.

The spectrum of the transmitted biphase-coded radio-data signal is shown in Fig.3(a) and the time-function of a single biphase symbol (as transmitted) in Fig-3(b).

In the present BBC experimental radio-data source equipment the biphase symbols are generated by direct digital synthesis of the transmitted waveform. This ensures precise and stable spectrum shaping.

The d.s.b.s.c. a.m. 57 kHz radio-data signal waveform at the output of the BBC experimental radio-data source equipment may be seen in the photograph of Fig-3(c).

2.7 Demodulation of the Data Signal.

The processes involved in demodulating and decoding the data signal from the composite multiplex signal at the f.m. discriminator output are indicated schematically in Fig.2. These are:

* *The data spectrum shaping filtering has been split equally between the transmitter and receiver (to give optimum performance in the presence of random noise) so that, ideally, the data shaping filter at the receiver should be identical to that at the transmitter (i.e. as given above in Equation (3)). The overall data channel spectrum shaping would then be 100% cosine roll-off which satisfies Nyquist's three requirements for zero intersymbol interference*[5].

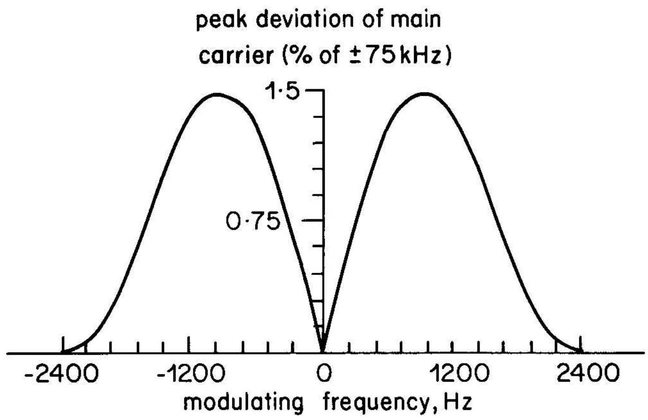


Fig 3 *(a)* Spectrum of biphase coded radio-data signals

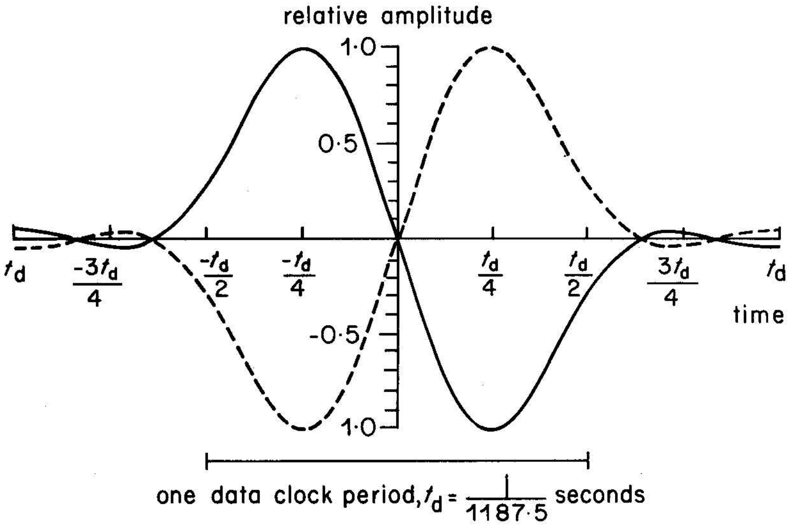


Fig 3 *(b)*
Time-function of a single biphase symbol

—— symbol generated when the data input bit (after differential coding) is a logic 1

- - - symbol generated when the data input bit is a logic 0

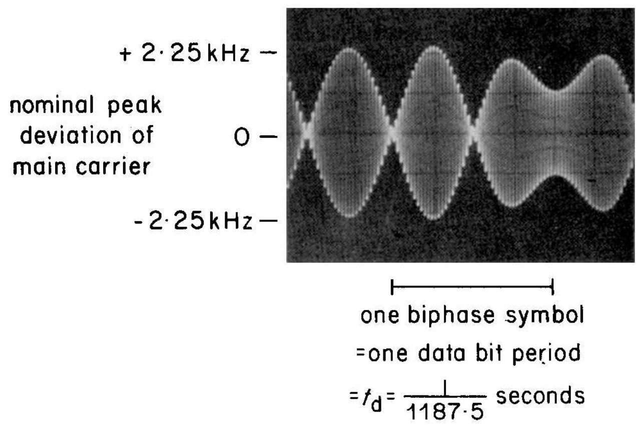


Fig 3 *(c)* D.s.b.s.c.a.m. 57 kHz radio-data signals

1. Recovery of a phase-locked 57 kHz subcarrier to enable the data modulated subcarrier to be synchronously demodulated.
2. Recovery of the NRZ data waveform from the biphase symbols, and the associated bit-rate clock.
3. Decoding of the differentially encoded data.

2.7.1 Subcarrier Recovery and Demodulation.

The first step in decoding the received radio-data signal from the composite multiplex signal at the output of the v.h.f./f.m. receiver discriminator is to demodulate the 57 kHz d.s.b.s.c. a.m. signal. To achieve this it is usually necessary to recover a coherent 57 kHz subcarrier from the received radio-data signal.*

Since the transmitted d.s.b.s.c. a. m. radio-data signal contains no component at the subcarrier frequency one of the standard techniques for recovering the suppressed-carrier from a d.s.b.s.c. a. m. (or p.s.k.) signal must be used, e.g. a squaring circuit, Costas loop or decision feedback[6].It is very important to the performance of the decoder that the recovered 57 kHz subcarrier should be stable and jitter-free even when the received radio-data signal is noisy.

Demodulation of the 57 kHz radio-data signal is then simply achieved using a multiplier or synchronous demodulator. Although a switching multiplier may be used it is important that the path between the 57 kHz radio-data signal input and the demodulated signal output is essentially linear, i.e. there must be no limiting action in the demodulator. This is necessary if optimum performance in the presence of noise is to be achieved.

It may be noted that whilst, in theory, no filtering is needed before the demodulator, in practice a 57 kHz bandpass filter before the demodulator (see Fig.2) is desirable to attenuate the comparatively large-amplitude sound-signal components in the multiplex signal. This filter must not, of course, cause distortion to the 57 kHz radio-data signal.

2.7.2 Biphase Symbol Decoding and Bit-rate Clock-recovery.

The optimum technique for decoding the biphase symbols would be a correlation decoder[6]. This would, however, require the development of rather specialised circuitry and might, initially at least, be rather expensive to implement. Fortunately, however, there is little penalty for using a simpler suboptimal biphase decoding technique such as the integrate and dump decoder[7],[8] shown in outline in Fig.2.**

* *Differential demodulation[6] might alternatively be used. Here an analogue delay-line is used to permit the subcarrier phase-change in adjacent data-bit periods to be detected directly. This technique does not require a coherent subcarrier reference in the receiver but usually suffers from poor performance in the presence of noise.*

** *Such an integrate and dump decoder has a theoretical noise penalty of only 0.9 dB compared with an optimal correlation or matched filter decoder[7].*

(See also Section 2.8 and Fig. 4).

All decoding techniques require the recovery of the 1187.5 Hz bit-rate clock. With biphase coded data this is relatively easy since there are always plenty of zero-crossings in the data stream regardless of its message content. However, it must be noted that the biphase data stream does not contain a coherent component at 1187.5 Hz and thus it cannot be used to phase-lock a bit-rate clock directly. There are, however, many standard techniques for recovering the clock from biphase data (see for example references (7) and (8)).

Here advantage can be taken of the fact that (except for the occasional inserted or deleted 57 kHz cycles (see Section 2.4)), the bit-rate is an exact integral divisor (48) of the subcarrier frequency. Thus, all that the bit-rate clock-recovery circuit has to do is to correctly phase the 1187.5 Hz clock (obtained by dividing down the recovered 57 kHz subcarrier) relative to the zero-crossings of the recovered biphase coded data-stream.

2.7.3. Differential Decoding.

Differential decoding of the recovered non-return to zero (NRZ) binary data stream must be performed according to the rules given in Section 2.5. This is easily implemented with the circuit shown in outline in Fig.2.

2.8 Bit-Error Rate.

The bit-error rate to be expected at the output of an ideal radio-data decoder, when the only transmission impairment is thermal noise due to low field-strength, is plotted as a function of the open-circuit input e.m.f. from a 75 ohm source into the aerial input of the v.h.f. receiver as curve (a) in Fig.4. Details of the calculation are given in Appendix 1. A noise figure of 7 dB was assumed for the v.h.f. receiver in these calculations.

For the purposes of comparison, the measured error-rate obtained with a simple integrate and dump decoder (of the type described in Fig.2 and Section 2.7) is plotted as curve (b) in Fig.4. The noise figure of the v.h.f. receiver used in these measurements was 7dB.

Also plotted in Fig.4 as curve (c) is the mono peak-signal-to-peak-weighted-noise ratio* (measured according to CCIR Recommendation 468) obtained in the sound programme channel of the same v.h.f. receiver used in the error-rate measurements of curve (b). This was measured after 50 µs de-emphasis relative to a + 8 dBm0 tone at 440 Hz (i.e. ± 53.62 kHz deviation with standard BBC line-up levels).

3. DATA FORMAT

3.1 Block Structure.

The transmitted data stream is partitioned into blocks of total length 114 bits each (see Fig.5). The first four bits of each block contain an address to specify the block type (out of 16 possible types, numbered 0 to

* *As a guide it may be noted that (interpreting from CCIR Recommendation 412-2) the minimum open-circuit aerial e.m.f. for satisfactory mono reception is usually taken as being about 34 dB µv. For satisfactory stereo reception about 54 dB µv is needed.*

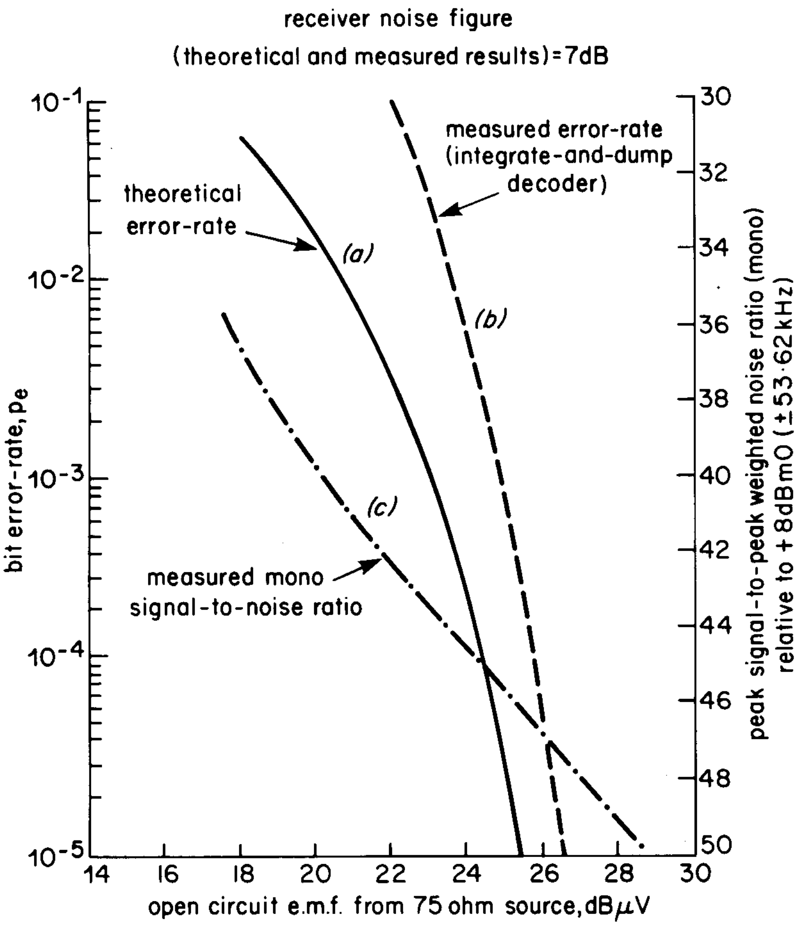


Fig 4. Bit error-rate and mono signal-to-noise ratio in a radio-data receiver

15) and thus define the type of message to be expected within the block. Sub-addressing within any one block type may also be used to expand the system beyond the sixteen basic types of block.

The last sixteen bits of each block are allocated to a cyclic redundancy (CRC) checkword d which is used to enable the receiver/decoder to test for corruption of the received data by errors during transmission. This CRC will be described in detail in Section 3.3.

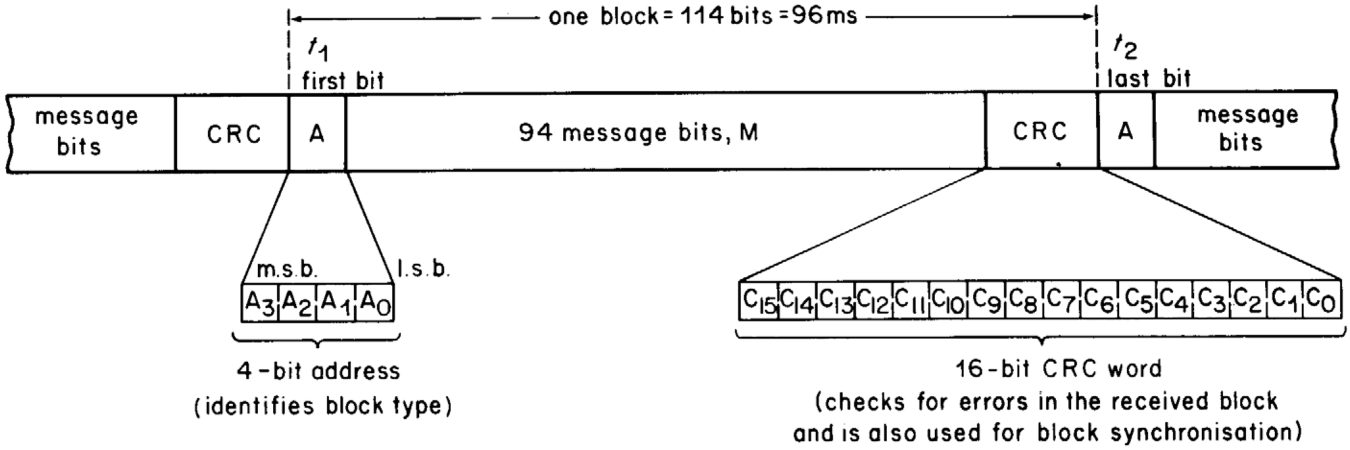
The CRC also serves to provide a means of identifying the beginning and end of each block (i.e. block synchronisation), as will be described in Section 3.4.

Each block is a self-contained 'packet' and can be decoded independently of blocks adjacent to it. Thus maximum flexibility for interleaving blocks of different types is obtained, permitting a wide range of applications to be serviced simultaneously.

Independence of the blocks also ensures maximum immunity to errors because errors in one block cannot cause errors in another.

The block length of 114 bits was chosen for two reasons: -

1) Theory and experiment had shown that for optimum data throughput efficiency in the presence of multipath propagation (which was found



1) A = Block Type address = 4 bits (see Section 4-2)

2) M = Message = 94 bits (see Section 4)

3) CRC = Cyclic redundancy check word = 16 bits (see Sections 3-3 and 3-4)

Total Block Length = 114 bits

4) $t_1 < t_2$, i.e. the Block Type address for a particular block is transmitted first and the CRC word last.

Fig 5 Structure of radio-data blocks

to be the major limiting factor for radio-data reception in vehicles) a block length of about 100 bits was needed. With shorter blocks the percentage overhead for check-bits and header codes increased whilst with longer blocks the proportion of blocks received error-free decreased.

2) When transmitting clock-time information it is convenient to have an integral number of blocks per minute, so that the minute-marker is always in the same position in the block. With a data rate of 57000/48 = 1187.5 bit/s there are exactly 625 x 114 bit blocks per minute.

3.2 Order of Bit Transmission.

All codewords, checkwords, binary numbers or binary address values have their most significant bit (m.s.b.) transmitted first (see Fig.5). Thus the last bit transmitted in a binary number or address has weight 2^0.

The data transmission is fully synchronous and there are no gaps between the blocks.

3.3 Error Protection.

Each transmitted block contains a 16-bit (CRC) word. This checkword is the sum (modulo 2) of:

1) The remainder after multiplication by x^{16} and then division (modulo 2) by the generator polynomial g(x), of the 98-bit message string (including the four-bit block type address).

2) The remainder of x^{98} $(x^{15} + x^{14} + x^{13} + \ldots + x^2 + x + 1)$ divided (modulo 2) by the generator polynomial g(x).

Where the generator polynomial g(x) is given by

$$g(x) = x^{16} + x^{12} + x^5 + 1$$

It may be noted that adding the second term above is equivalent to inverting the first sixteen bits of the message string which in turn is equivalent to pre-setting the division register to 'all-ones'. The purpose of this pre-setting is to avoid 'all-zeroes' strings (no data signal present) from being falsely accepted as valid data by the receiver. It also helps with block synchronisation in the receiver (see the next Section).

The CRC word thus generated is transmitted m.s.b. (i.e. the coefficient of x^{15} in the remainder) first and is transmitted at the end of the block which it protects.

The above description of the CRC may be regarded as definitive but further explanatory notes on the implementation of the CRC encoder are given in Appendix 2-1.

In the receiver/decoder the received blocks are checked by using an identical division circuit to that at the transmitter. The initial remainder of the decoder division register is preset to the 'all-ones' state before reading-in the first bit of a received block. All 114 bits of the received data block (including the received CRC word) are then read serially into the division register. In the absence of transmission errors the remainder in the division register will be 'all-zeroes' at the end of the block.

This error-checking procedure is similar to that used in HDLC*/SDLC** applications as described in ISO 3309-1976, but there are some important differences from the system described there. These arise principally because we are working with fixed-length blocks and hence do not need to flag the ends of blocks separately.

One major difference is that in ISO 3309-1976 the CRC words are inverted before transmission and a non-zero remainder results in the absence of errors whereas here the CRC is not inverted before transmission. The generator polynomial used here is, however, an industry standard and is defined in CCITT Recommendation V41 (Geneva 1972) (and is usually known as CRCC-CCITT Forward). Standard integrated circuits exist for its coding and decoding (including the presetting to the 'all-ones' state). Examples of the CRC words for three specific message strings are given in Appendix IV.

Explanatory notes on the implementation of the CRC decoder are given in Appendix 1-2.

The CRC has the following error-checking properties [(9)]:

1) Detects all single, double, triple and all odd errors.

2) Detects all error bursts of length 15 bits or less.

3) Detects 99.998% of all longer bursts.

* *High-level data link control*

** *Synchronous data link control*

The code is also capable of correcting single errors but it is not intended that this error-correction capability should be used in radio-data reception. This is because the use of the error-correcting properties of the code in a receiver/decoder greatly increases the undetected error-rate (since many uncorrectable error patterns are deemed correctable and thus pass undetected). Furthermore the correction of single errors would yield negligible improvement because the differential coding and decoding of the radio-data causes the errors to occur in pairs.*

Thus it is intended that erroneous blocks should be discarded and correction achieved by relying upon the fact that the messages will usually be repeated quite frequently.

3.4 Synchronisation of Blocks.

In the receiver/decoder it is, of course, necessary to be able to recognise the beginnings and ends of the data blocks i.e. provision of block synchronisation. Conventionally this is achieved by adding a header code to each transmitted block and ensuring that, with sufficiently high probability, the message data does not mimic the header code. The penalty for using this simple system is the overhead in transmitting the header code plus any packing bits needed to avoid mimicking of the header code by the data.

A more efficient scheme is to code the transmitted blocks in such a way that the error-check in the receiver/decoder will detect block synchronisation slip as well as additive errors. Cyclic or shortened cyclic codes are not suitable for this purpose (unless they are modified - see below) because of the fundamental weakness that cyclic shifts of code-words give rise to other code-words; thus the probability of detecting block synchronisation slip is quite small.

Random coset codes [10,11] (in which a randomly chosen binary sequence is added to each code word in a cyclic or shortened cyclic code), however, have good capability for detecting block-synchronisation-slip; it can be shown [5,10,11] that with n-k check bits, it is possible to make the probability that synchronisation loss is undetected as small as 1 in $2^{(n-k)}$.

The operations on the cyclic code-words are all reversible at the receiver and so the normal (additive) error-detecting ability of the code is unaffected. Furthermore, with a suitably chosen random coset cede synchronisation loss can be reliably detected even in the presence of errors.

It may be shown that[10,11] a random coset code can most simply be generated by pre-setting the encoder of a cyclic or shortened cyclic code to some chosen non-zero state before encoding the first information bit of each block. At the receiver the code-words may be decoded by presetting the decoder to the same non-zero state prior to the reception of the first bit in each block.

Here the encoder and decoder are both preset to the 'all-ones' state as described in the previous Section. It is found that the probability of synchronisation slip remaining undetected is (for random data) 1 in 2^{16}.

* *Even if this were not the case, detailed studies of the statistics of the errors in radio-data have shown that the errors tend to occur in dense bursts.*

The principle, therefore, whereby block synchronisation is obtained and maintained is that, with a high level of confidence, a zero remainder in the decoder division-register will result only once for each block received and will occur precisely at the end of each complete block. This block synchronisation system is described in Appendix III.

4. MESSAGE CONTENT

4.1 Structure

The message structure proposed here is intended to provide a high degree of freedom in assembling the information in almost any way and proportion to suit the programmes on a particular network at any given time and to allow for future developments in receivers. There is thus no fixed pattern of occurrence or repetition for various block types and hence it is not possible to describe any fixed message structure beyond that of the various types of block.

It may be noted that experience with UK teletext (which has a similar flexible structure) has proved the immense value of a flexible structure which can instantly be changed to accommodate both the expected and unexpected[12].

One feature of the message content which is fixed is, however, the Basic Information Phrase (BIP). This, as will be described, is a short (20 bits) code designed to give a radio-data receiver/decoder the basic control information needed for search tuning and similar automatic functions. To obtain fast search times and reliable operation under poor reception conditions it is desirable to repeat the BIP as often as possible.

Thus the BIP is included in the same position in every block regardless of type. This periodicity in the occurrence of the BIP should simplify decoding and perhaps make feasible a low-cost, BIP-only decoder.

4.2 Block Types

As was described in Section 3.1 (see also Fig-5) the first four bits of every block are allocated to a four-bit address which specifies the block type.

In the present experimental system, only two block types will be transmitted viz:-

<table>
<tr><th colspan="2">Block Type</th><th rowspan="2">Application</th></tr>
<tr><th>Binary Code
A_3 A_2 A_1 A_0</th><th>Decimal Value</th></tr>
<tr><td>0 0 0 0</td><td>0</td><td>Network and Programme Identification</td></tr>
<tr><td>1 1 1 1</td><td>15</td><td>Dummy blocks with pseudo-random data (except for the BIP see below)</td></tr>
</table>

(N.B. A_3 is the first transmitted bit of the block.)

The remaining 14 block types will be specified at a later date when possible applications have been defined. It may be noted that some block types may include sub-addressing to permit branching beyond the 16 basic types of block.

4.2.1 'Type 0' Blocks

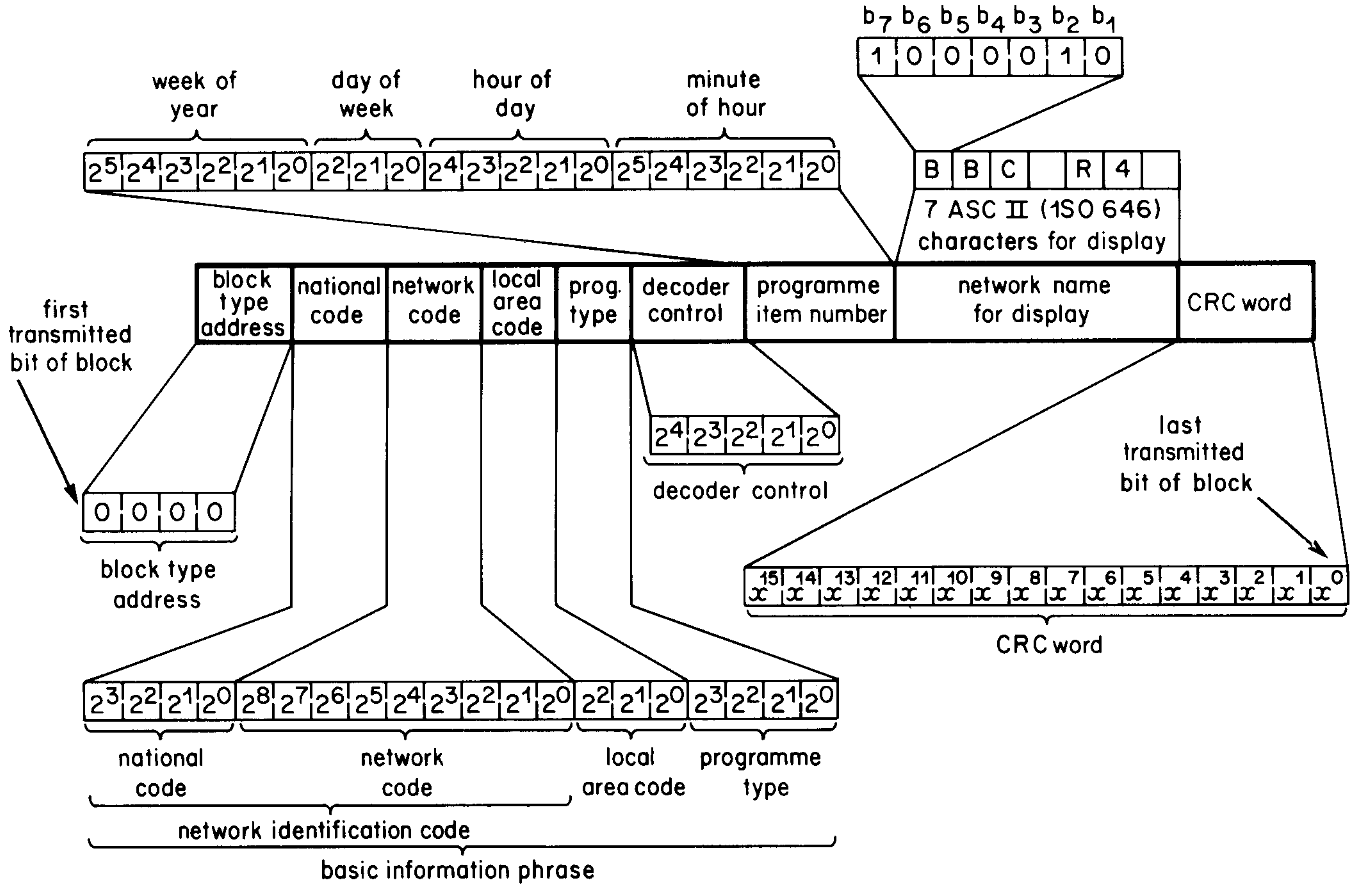
It is expected that 'Type 0' blocks will be transmitted about once per second in a final system. In the present simple experimental system, one block in ten will be a Type 0 block. (Thus giving a repetition rate slightly higher than once per second).

The format of Type 0 blocks is illustrated in Fig. 6 and may be seen to contain the following items:

Item	Number of Bits		
Block Type Address Code	4		
National Code	4	Network Identification Code	Basic Information Phrase (BIP)
Network Code	9		
Local Area Code	3		
Programme Type Code	4		
Decoder Control Code	5		
Programme Item Number (schedule start-time)	20		
Network name for display (7 ASCII characters)	49		
CRC word	16		
TOTAL	114 bits		

The first 20 bits alter the Block Type address comprise the Basic Information Phrase (BIP) which, as noted above, is also included in the same position in all other types of block.

The first 13 bits of the BIP comprise a Network Identification Code which



Notes on Type 0 Blocks

1) The Programme Item Number is its scheduled broadcast time and date expressed in terms of coordinated Universal Time.

Week number in the range 1 to 53 is coded directly as a six-bit binary number. The spare codes are not used.
Day-of-week is coded as a three-bit binary number, 001 = Monday to 111 = Sunday consecutively. Code 000 is not used.
Hours are transmitted as a five-bit binary number in the range 0 - 23. The spare codes are not used.
Minutes are transmitted as a six-bit binary number in the range 0 - 59. The spare codes are not used.

2) The Network Name (for display) is transmitted as 7 bit ASCII Characters (as defined in the international version of the 7 bit code table in ISO-646-1973).
Seven characters (including spaces) are allowed for each network. Unfilled character slots at the beginning or end of the name must be filled with the ASCII 'space' character.
The characters are transmitted in language order (left-to-right as written on the page).
The m.s.b. (b_7) of each character is transmitted first.

Fig 6 Format of type 0 blocks

is split into a National Code identifying the country* broadcasting the programme and a Network Code identifying the particular network within that country.

Thus, for example, the National Code for the United Kingdom might be 0 and 134 the Network Code for BBC Radio 4 (where in both cases the numbers are hexadecimal). Thus the complete Network Identification Code for BBC Radio 4 UK would be 0134 (hex).

It is the intention that the Network Identification Code would identify a programme source (i.e. a programme network rather than a particular transmitter). Thus all relay stations would carry the same Network Identification Code as the main transmitter.

The Network Identification Codes used in the present BBC experimental radio-data broadcasts are described in Appendix IV, together with details of the data in other parts of the blocks.

The next 3 bits of the BIP comprise a Local Area Code which is used to identify particular local transmitters broadcasting a given network. For details of the Local Area Codes see Appendix IV.

The last 4 bits in the BIP identify the generic programme type (e.g. traffic announcement, news etc.) and this code is intended to aid the receiver in searching for a particular programme type, independent of network.

A typical application of these codes might be: -

Programme type code (hexadecimal)	Application
0	Traffic Announcement
1	News Bulletin
2	Weather Forecast
3	Sport
4	Light Music
5	Classical Music
6	Pop Music
7	Drama
8	Current Affairs
9	Special Broadcast (e.g. Olympics, General Election coverage, etc. (redefinable label))
A	Public emergency-alarm
B-F	Reserved for future use

* *Since there are only 16 possible National Codes this code may not, of course, be uniquely applied to one country in the world. Rather it is intended to distinguish between bordering countries (see also notes in this Section on character coding tables).*

These definitions must necessarily be very tentative at present. However, it may be noted that use of the Traffic Announcement Code (Code 0) could serve the same function as the ARI message tone (see CCIR Document 10/198 (1970-74)).

Code 9 would be a redefinable label used to identify any special broadcast or series of broadcasts (e.g. General Election coverage) which the listener may wish to follow.

Code A is intended to serve as an Alarm Code in the event of a public or national emergency, (e.g. flooding) and might be used to sound an alarm tone to advise the listener to listen to his receiver.

Details of the Programme Type Codes are given in Appendix IV.

The remaining items in the block occur only in Type 0 blocks and are thus repeated only about once per second.

The first of these items (see Fig.6) is five bits long and is allocated to decoder control. Typical applications of this might be as follows:-

Binary Code					Typical Application
D_4	D_3	D_2	D_1	D_0	
1	X	X	X	X	Music
0	X	X	X	X	Speech
X	X	X	0	0	Mono
X	X	X	0	1	Stereo
X	X	X	1	0	Binaural
X	X	X	1	1	Quad

X indicates that the bit may be 0 or 1.

N.B. D_4 is transmitted first.

Thus bit D_4 indicates whether the programme is music or speech and would enable the listener to set his own music/speech balance by having one volume control active with $D_4 = 1$ (for music) and another for $D_4 = 0$ (for speech).

Bits D_0 and D_1 are used to indicate the coding of the sound-signal, i.e. mono, stereo binaural etc. and thus activate the appropriate decoding process in the receiver.

Bits D_2 and D_3 are reserved for future use.

Details of the Decoder Control Codes are given in Appendix IV.

The next 20 bits in the Type 0 blocks will be allocated to the Programme Item Number (for the current programme on this network. This Programme Item Number is simply its scheduled broadcast start-time (expressed in terms of Coordinated Universal Time UTC) - see CCIR Recommendation 460 (Geneva 1974), ISO 2015 (week numbering) and ISO 2014 (representation of calendar dates for the information interchange)).

Thus the scheduled broadcast time of the current programme is expressed in terms of week of year, day of week, hour of day and minute of hour, as indicated in Fig.6*. It is intended that once a programme is scheduled it should be broadcast with its original schedule start-time even though it may actually be broadcast at some other time and date than that scheduled**. This is necessary to avoid ambiguity if the listener preselects programmes from published schedules and ensures that the Programme Item Number (for a given network) is unique within a timespan of one year.

Details of the Programme Item Numbers are given in Appendix IV.

The remaining 49 bits of each Type 0 block will be used to transmit the Network name (for display) as 7 x 7 bit ASCII characters.

For the current BBC experimental radio-data transmissions the ASCII code table which will be used for the displayed 7-bit coded characters is the international reference version of the code table defined in ISO 646-1973. For convenience this code table is produced here as Table 1. It should be noted that the radio-data applications of the control characters in columns 0 and 1 of the Table have yet to be defined.

There exists the possibility that national variants of this code table might be used by other countries t o accommodate different characters (e.g. in Scandinavian languages) or even different alphabets (e.g. Cyrillic). The radio-data decoder could then switch between code tables according to the National code in the BIP.

It should be noted that the ASCII characters are transmitted most significant bit (m.s.b.) (i.e. b_7) first which contradicts the convention used in line data transmission (e.g. see CCITT Recommendation V4, Green Book Volume VIII) and UK teletext[12] but accords with the standard adopted here for all other types of data (addresses, checkwords, dates, times, etc. are all transmitted m.s.b. first).

An alternative to displaying the Network Name might be to use a voice synthesiser to speak the name. This might be particularly applicable to car-radios where a display would be distracting. Again it would be possible to use the National code in the BIP -in this case to change the accent and pronounciation according to the broadcasting country.

Details of the Network Names are given in Appendix IV.

4.2.2 Type 15 Blocks

For the time being, Type 15 blocks (block type address 1 1 1 1) are transmitted in nine blocks out of every ten in the present BBC

* *N.B. week of year, day of week etc. are all binary (not B.C.D.) numbers.*

** *Because of this the Programme Item Number cannot be used to derive clock-time or date information.*

				b_7	0	0	0	0	1	1	1	1
				b_6	0	0	1	1	0	0	1	1
				b_5	0	1	0	1	0	1	0	1
b_4	b_3	b_2	b_1	row \ col	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
0	0	0	0	**0**	NUL	TC_7 (DLE)	SP	0	@	P	`	p
0	0	0	1	**1**	TC_1 (SOH)	DC_1	!	1	A	Q	a	q
0	0	1	0	**2**	TC_2 (STX)	DC_2	"	2	B	R	b	r
0	0	1	1	**3**	TC_3 (ETX)	DC_3	#	3	C	S	c	s
0	1	0	0	**4**	TC_4 (EOT)	DC_4	¤	4	D	T	d	t
0	1	0	1	**5**	TC_5 (ENQ)	TC_8 (NAK)	%	5	E	U	e	u
0	1	1	0	**6**	TC_6 (ACK)	TC_9 (SYN)	&	6	F	V	f	v
0	1	1	1	**7**	BEL	TC_{10} (ETB)	'	7	G	W	g	w
1	0	0	0	**8**	FE_0 (BS)	CAN	(	8	H	X	h	x
1	0	0	1	**9**	FE_1 (HT)	EM	)	9	I	Y	i	y
1	0	1	0	**10**	FE_2 (LF)	SUB	*	:	J	Z	j	z
1	0	1	1	**11**	FE_3 (VT)	ESC	+	;	K	[	k	{
1	1	0	0	**12**	FE_4 (FF)	IS_4 (FS)	,	<	L	\	l	|
1	1	0	1	**13**	FE_5 (CR)	IS_3 (GS)	-	=	M	]	m	}
1	1	1	0	**14**	SO	IS_2 (RS)	.	>	N	^	n	‾
1	1	1	1	**15**	SI	IS_1 (US)	/	?	O	_	o	DEL

Note:-

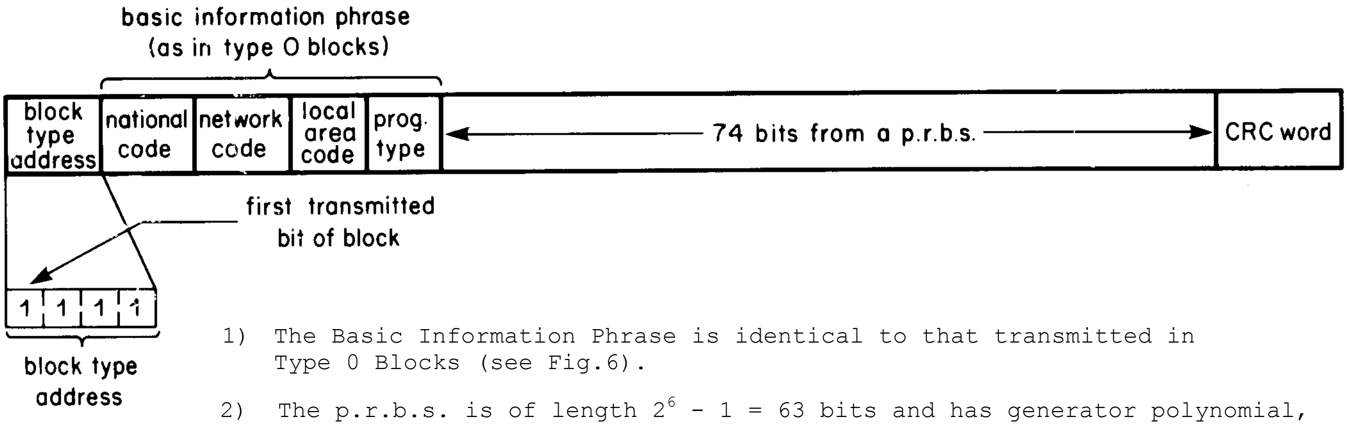
Details of the control characters defined in columns 1 and 2 in the table may be found in ISO 646-1973.
Their precise application in radio-data has yet to be defined.

Table 1. International reference version of ISO 646 code table

experimental radio-data broadcasts. They are dummy blocks and apart from the BIP (which occupies the same position, of course, as it does in Type 0 blocks) they are filled by data from a 63-bit pseudo-random binary sequence (p.r.b.s.) generated by:

$$F(x) = x^6 + x + 1$$

The structure of these blocks is illustrated in Fig.7.



1) The Basic Information Phrase is identical to that transmitted in Type 0 Blocks (see Fig.6).

2) The p.r.b.s. is of length $2^6 - 1 = 63$ bits and has generator polynomial, F(x)given by

$$F(x) = x^6 + x + 1$$

The 74-bit segments of the p.r.b.s. transmitted in successive Type 15 blocks form a continuous sequence.

Fig 7 Format of type 15 blocks

It may be noted, however, that the CRC word transmitted in these blocks is valid for the data which they contain - thus they may be decoded as for any other block type.

The p.r.b.s. generator is stopped between transmissions of Type 15 blocks and thus by recovering the 74 p.r.b.s. data bits from each transmitted block a continuous sequence may be reconstructed. This might be used to make measurements of the bit error-rate in the received data.

5. CONCLUSIONS

The report has described the data channel parameters and message format for a v.h.f. radio-data system using d.s.b.s.c. a. m. modulation of a 57 kHz subcarrier by biphase coded data at about 1187.5 bit/s.

The transmitted data are partitioned into blocks of 114 bits each which are transmitted synchronously without gaps. Each block is a self-contained data packet containing an address which enables it to be decoded independently of other blocks.

Error protection is provided by a powerful 16-bit modified cyclic redundancy check which reliably detects about 99.998% of all possible error patterns. Correction is achieved by discarding erroneous blocks and relying upon repetition of the transmitted messages.

This same modified cyclic code also provides block synchronisation information without the need for a dedicated header code.

The proposed addressing structure gives the proposed system the flexibility to service a wide range of applications and gives the broadcaster the freedom to assemble the information in any way and any proportion to suit the needs of particular programmes. This approach will also allow the system to evolve gradually as new applications become apparent.

This independence of blocks also ensures maximum immunity to errors because errors in one block cannot cause errors in another.

The experimental radio-data system currently on-air from three BBC v.h.f. transmitters in the London area uses a small amount of the available data-channel capacity to transmit blocks containing the most likely types of message, including the station name (in ASCII) for display. The remaining channel capacity is at present packed with dummy (but valid) blocks.

As the specification for other block types and applications are decided upon the dummy blocks will be replaced with more representative data including these new block types.

6. REFERENCES

1. MacEWAN, D. 1977. 'Radio in the 80s', Wireless World, 1977, 83, 5, PP-36-40

2. WHYTHE, D.J., and ELY, S.R. 1978. 'Data and identification signalling for future radio receivers', International Broadcasting Convention 1978, I.E.E. Conference Publication No. 166, pp.324-326.

3. MAKITALO, 0. 1978. 'Utilisation of the f.m. broadcasting network for transmission of supplementary information', International Broadcasting Convention 1978, I. E. E. Conference Publication No.166, pp.327-329.

4. PEEK, J.B.H., and SCHMIDT, J.M. 1978. 'A "Station Programme Identification" (S.P.I.) for f.m. sound broadcasting', I.E.E. Conference Publication No.166, pp.321-323.

5. BENNETT, W.R., and DAVEY, J. R. 1965. 'Data transmission', New York, McGraw-Hill, 1965.

6. LINDSEY, W. C., and SIMON M.K. 1973. 'Telecommunication systems engineering', Englewood Cliffs, N.J., Prentice-Hall, 1973.

7. FRENCH, R. C. 1976. 'Error performance of p. s. k. and f .f . s. k. subcarrier data demodulators',. The Radio and Electronic Engineer, 1976 46, 11, pp.543-548.

8. NORTON, J.J. 1979. 'Drop your costs but not your bits with a Manchester-data decoder', Electronic Design (USA, 1979, 27, 15, pp.110-116.

9. PETERSON, W.W., and BROWN, D.T. 1961. 'Cyclic codes for error detection', Proc.I.R.E., 1961, 49, 1, pp.228-235.

10. HELLMAN, M.E. 1975. 'Error detection in the presence of synchronisation loss', I.E.E.E. Trans.Commun., 1975, COM-23, 5, pp.538-539.

11. HELLMAN, M.E. 1974. 'Error detection made simple', International Conference on Communication 1974, Conference Record, pp.9A1-9A4.

12. CHAMBERS, J. P. 1980. 'Enhanced U.K. teletext moves towards still pictures', BBC Research Department Report No.1980/4.

13. SCHWARTZ, M., BENNETT, W.R., and STEIN, S. 1966. 'Communication systems and techniques', New York, McGraw-Hill, 1966.

14. RICE, S.O. 1963. 'Noise in f.m. receivers', in 'Time Series Analysis' edited by M. Rosenblatt, New York, John Wiley,1963.

15. ABRAMOWITZ, M., and STREGUM, I.A. 1965. 'Handbook of mathematical functions', Power Publications, 1965, Table 26-1, pp.966-972.

Appendix 1

Calculation of the Bit Error Rate at the Output of the Radio-Data Decoder

A1-1 General

In this Appendix we calculate the bit-error-rate to be expected at the output of an ideal radio-data decoder when the only transmission impairment is thermal noise due to low field-strength. The analysis is necessarily fairly complicated and every attempt has been made to simplify the problem by making suitable approximations.

A1-2 Calculation of the Peak Data Signal-to-r.m.s. Noise Ratio

Let f_b be the bandwidth occupied by the d.s.b.s.c. a.m. radio-data signal. Here this is equal to 1187.5 Hz and let:

a = r.m.s. amplitude of the r.f. carrier measured as a p.d. across the receiver aerial input (volts).

p_n = spectral density of the thermal noise at the receiver input (volts^2/Hz).

f_{sc} = radio-data subcarrier frequency (Hz)

= 57,000 Hz

Δf = peak deviation of the v.h.f. carrier due to the modulated radio-data subcarrier (Hz).

≈ 2250 Hz

Now the spectral density of the thermal (Johnson) noise of the receiver input is given by:

$$p_n = kTR \text{ volts}^2\text{/Hz} \qquad \text{..........(1)}$$

where

k = Boltzmann's Constant = 1.38×10^{-23} JA

T = Temperature, which we assume to be 290 K

R = Effective resistance across the receiver aerial input

= 75 ohms

Assuming for the present an ideal f.m. receiver (noise Figure F = 0 dB) the noise power density at the output of the f.m. discriminator is approximately given by (for high signal-to-noise ratio well above the f.m. thresholds (see reference (13) for derivation)):

$$S_o(f) = \frac{2p_n f^2 D^2}{a^2} \quad \text{volts}^2/\text{Hz} \qquad \text{..........(2)}$$

where D is the gain constant of the f.m. discriminator (volts/Hz).

Thus the total noise power in the subcarrier channel (before demodulation of the d.s.b.s.c. a.m. signal) centred on 57 kHz and with f_b is given by:

$$N = \frac{2p_n D^2}{a^2} \int_{f_{sc} - \frac{f_b}{2}}^{f_{sc} + \frac{f_b}{2}} f^2 \, df \qquad \text{..........(3)}$$

$$\approx \frac{2p_n f_{sc}^2 f_b D^2}{a^2} \quad \text{volts}^2 \qquad \text{..........(4)}$$

Thus the r.m.s. noise level at the f.m. discriminator output measured in bandwidth f_b centred on 57 kHz is given by:

$$\sigma_S = \frac{f_{sc} D}{a} \sqrt{2p_n f_b} \quad \text{volts} \qquad \text{..........(5)}$$

The peak amplitude of the modulated radio-data subcarrier at this point is given by:

$$h_S = \Delta f D \text{ volts} \qquad \text{........... (6)}$$

Now with an ideal synchronous demodulator for the 57 kHz subcaxrier and matched filtering or correlation detection for the biphase symbols the r.m.s. noise at the input to the data slicer (see Fig. 2) is then simply given by:

$$\sigma_B = \frac{2f_{sc} D'}{a} \sqrt{p_n f_b} \quad \text{volts} \qquad \text{..........(7)}$$

where D′ is the combined gain constant of the f.m. discriminator and the radio-data decoder up to the data slicer input.

The peak amplitude of the baseband data signal at this point is given by:

$$h_B = \Delta f D' \quad \text{volts} \qquad \text{..........(8)}$$

Thus the peak-signal-to-r.m.s.-noise ratio for an ideal receiver/decoder is given by:

$$\frac{h_B}{\sigma_B} = \frac{a \ \ \Delta f}{2f_{sc} \sqrt{p_n f_b}} \qquad \text{.........(9)}$$

With a real f.m. receiver with a noise figure $F \neq 0$ dB* this is degraded to:

$$\frac{h_B}{\sigma'_B} = \frac{a \, \Delta \, f}{2f_{sc}\left(\sqrt{p_n f_b}\right) 10^{(F/20)}} \qquad \text{..........(10)}$$

It must be noted, however, that this result is an approximation which is only valid well above the f.m. thresholds. At very low signal-to-noise ratios f.m. "clicks" (see reference (14)) rather than continuous noise will dominate and the instantaneous noise power will show strong dependence upon the instantaneous amplitude of the (composite) modulating signal.

A1-3 Calculation of the Bit-Error Probability

The probability of a bit-error before differential decoding (see Sections 2.5 and 2.7.3), p, can be written as:

p = ½ (probability that n(t) has magnitude greater than h_B)...... (11)

where n(t) is the instantaneous noise voltage at the data slicer input (see Fig. 2) and h_B is the peak amplitude of the data signal at the sample instant.

The factor of a half arises because the probability of n(t) having the right polarity to cause an error is a half.

The quantity n(t) is Gaussian (for signal-to-noise ratios well above thresholds) with r.m.s. value σ'_B (as given by Equation (10) in the previous Section) and it can be shown that (13) the probability that n(t) has magnitude greater than the data signal peak amplitude, h_B, is:

$$= 2\left(1 - P\left(\frac{h_B}{\sigma'_B}\right)\right) \qquad \text{..........(12)}$$

where

$$P(Z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Z} \exp\left(-Z^2/2\right) dZ \qquad \text{..........(13)}$$

P(Z) is the normal or Gaussian distribution function and is tabulated in Reference (15). Hence from Equation (11)

$$p = 1 - P\left(\frac{h_B}{\sigma'_B}\right) \qquad \text{..........(14)}$$

Now h_B/σ'_B is the peak-data-signal-to-r.m.s.-noise ratio as given by Equation (10) in the previous Section. Thus substituting in Equation (14) for h_B/σ'_B and using the tabulated values of P(Z) given in Reference (15) we may calculate the bit-error rate at the input to the differential decoder for any value of aerial input level, a.

* *In the calculations used to derive Fig.4 a noise figure F = 7 dB was assumed.*

Two further simple steps remain to obtain the results plotted in the graph of Fig. 4.

First we must convert the quantity 'a' (which is a measured p.d.) into an open-circuit e.m.f. and express it as decibels relative to one microvolt viz

Open circuit e.m.f. (from 75 Ω source) dB relative to 1 μv

$$= 20 \log_{10} 2a \text{ dB } \mu v \qquad \ldots\ldots\ldots (15)$$

where a is expressed in μv.

Second we must take account of the effect of the differential decoder. With differential decoding an error occurs if the present or previous data bit is wrong but not both. The probability of one error only in any pair of data bits is:

$$= 2p(1 - p) \qquad \ldots\ldots\ldots (16)$$

(where p is the bit-error rate at the input to the differential decoder).

Thus the bit-error rate at the output of the radio-data decoder is given by:

$$p_e - 2p(1 - p) \qquad \ldots\ldots\ldots (17)$$

where p is found from Equation (14) above.

Appendix II

Implementation and Theory of the Error Detecting Modified Cyclic Code

A2-1 Encoding

A definitive description of the CRC is given in Section 3.3.

Figure 8(a) shows a shift-register arrangement for encoding the transmitted 114-bit blocks. The procedure is as follows:

1. At the beginning of each block preset the 16-bit encoder shift-register to the 'all-ones' state.

2. With gates A and B enabled (i.e. data passes through) and gate C inhibited (data does not pass through) clock the 98-bit message string serially into the encoder and simultaneously out onto the channel.

3. After all the message bits for a block have been entered gates A and B are inhibited and gate C enabled. The shift-register is then clocked a further 16 times to shift the CRC word out onto the channel.

4. The cycle then repeats with the next block.

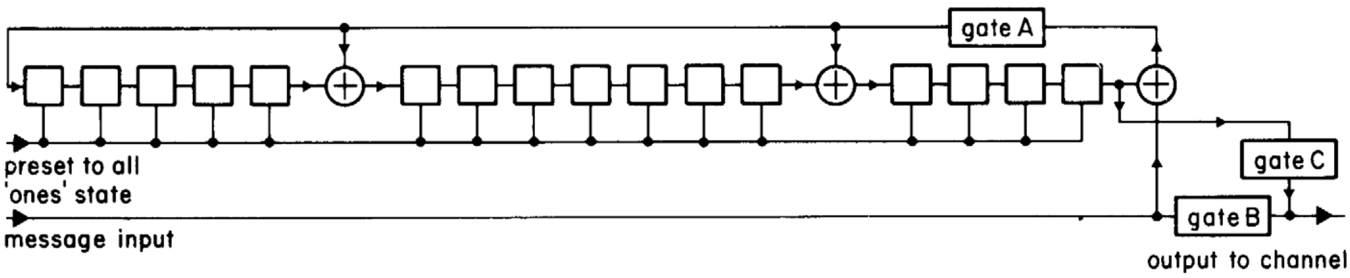


Fig 8 *(a)* Encoder for the modified cyclic code

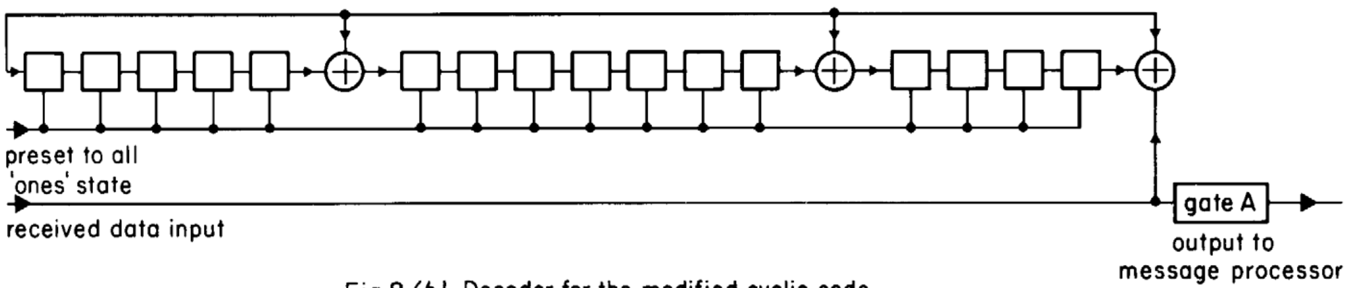


Fig 8 *(b)* Decoder for the modified cyclic code

If the polynomial $M(x) = x^{97} + x^{96} + \ldots + x + 1$ represents the 98-bit message string, then the CRC word is defined as the remainder, $R(x)$, obtained from the modulo-2 division of:

$$x^{16} M(x) + x^{98} (x^{15} + x^{14} + x^{13} + x^{12} + x^{11} + x^{10} + x^{9} + x^{8} + x^{7} + x^{6} + x^{5} + x^{4} + x^{3} + x^{2} + x + 1)$$

by the generator polynomial

$$g(x) = x^{16} + x^{12} + x^{5} + 1$$

i.e.

$$\frac{x^{16}\ M(x)\ +\ x^{98}\ (x^{15} + x^{14} + \ldots\ldots + x + 1)}{g(x)} = Q(x) + \frac{R(x)}{g(x)}$$

(where the quotient, Q(x), is discarded).

The multiplication of M(x) by x^{16} corresponds to shifting the message, M(x), 16 places and thus providing a space of 16 bits for the CRC word.

The addition of x^{98} $(x^{15} + x^{14} + \ldots\ldots + x + 1)$ to $x^{16}M(x)$ (equivalent to inverting the first 16 bits of $x^{16}M(x)$) corresponds to presetting the initial remainder to 'all-ones'.

At the transmitter the CRC word is added to the polynomial $x^{16}M(x)$ and results in a total message T(x) of length 114 bits, where $T(x) = x^{16}M(x) + CRC$ (where CRC is the 16-bit CRC word).

The CRC word is transmitted at the end of the block which it protects and the coefficient of x^{15} in the remainder (i.e. the first bit out of the encoder at the end of the division) is transmitted first.

A2-2 Decoding

Figure 8(b) shows a shift-register arrangement for decoding the error-check on the transmitted 114-bit blocks. The procedure is as follows:

1. At the beginning of each block preset the 16-bit decoder shift-register to the 'all-ones' state.

2. With gate A enabled clock the 98-bit message string serially into the decoder shift-register and simultaneously into a 98-bit buffer store in the message processor system.

3. After 98 clock pulses gate A is inhibited and the 16 bits of the CRC word are then clocked into the decoder. After 114 clock pulses the 16 storage stages of the decoder shift-register are examined. For an error-free block the contents will be zero and the 98-bit message can be accepted for processing.

A non-zero content in the decoder shift-register indicates that the block contains one or more errors and the 98-bit message must be discarded. Thus at the receiver the incoming 114-bit block, T(x), is multiplied by x^{16}, added to $x^{114}(x^{15} + x^{14} + \ .\ .\ .\ + x + 1)$ and divided b Y, the generator polynomial, g(x) (where g(x) is given by $g(x) = x^{16} + x^{12} + x^{5} + 1$), viz

$$\frac{x^{16}\ (x^{16}M(x) + CRC) + x^{114}(x^{15} + x^{14} + \ldots\ldots + x + 1)}{g(x)} = Qr(x) + \frac{Rr(x)}{g(x)}$$

Where the quotient Qr(x) is discarded and Rr(x) is the 16-bit remainder $(x^{15} + x^{14} + \ldots\ldots + x + 1)$ left in the decoder shift-register at the end of the decoding process. If the transmission is error-free this remainder is all zero (x^{15} through to x^{0}).

As in the encoder, the addition of $x^{114}(x^{15} + x^{14} + \ldots\ldots + x + 1)$ is equivalent to inverting the first 16 bits of $x^{16}T(x)$, and corresponds to presetting the initial remainder to a value of 'all-ones'.

Appendix III

Implementation of Block Synchronisation using the Modified Cyclic Code

A3-1 Derivation of Synchronisation Pulses

Figure 9 shows a block diagram of a shift-register arrangement for deriving block synchronisation information from the received data stream. It may be seen to comprise four main elements:

1. A 114-bit shift-register which may either act as a straight 114-bit delay (A/B input selector high) or as a recirculating shift-register (A/B input selector low).
2. A CRC decoder as described in Appendix 2-2 and Figure 8(b).
3. A fast free-running clock operating at at least 200 kHz.
4. A ÷ 116 counter with endstops, decoding for states 0, 1, and 115, and associated logic (gates 1 to 3 and flip-flops 1 to 3 (FF1 to FF3)).

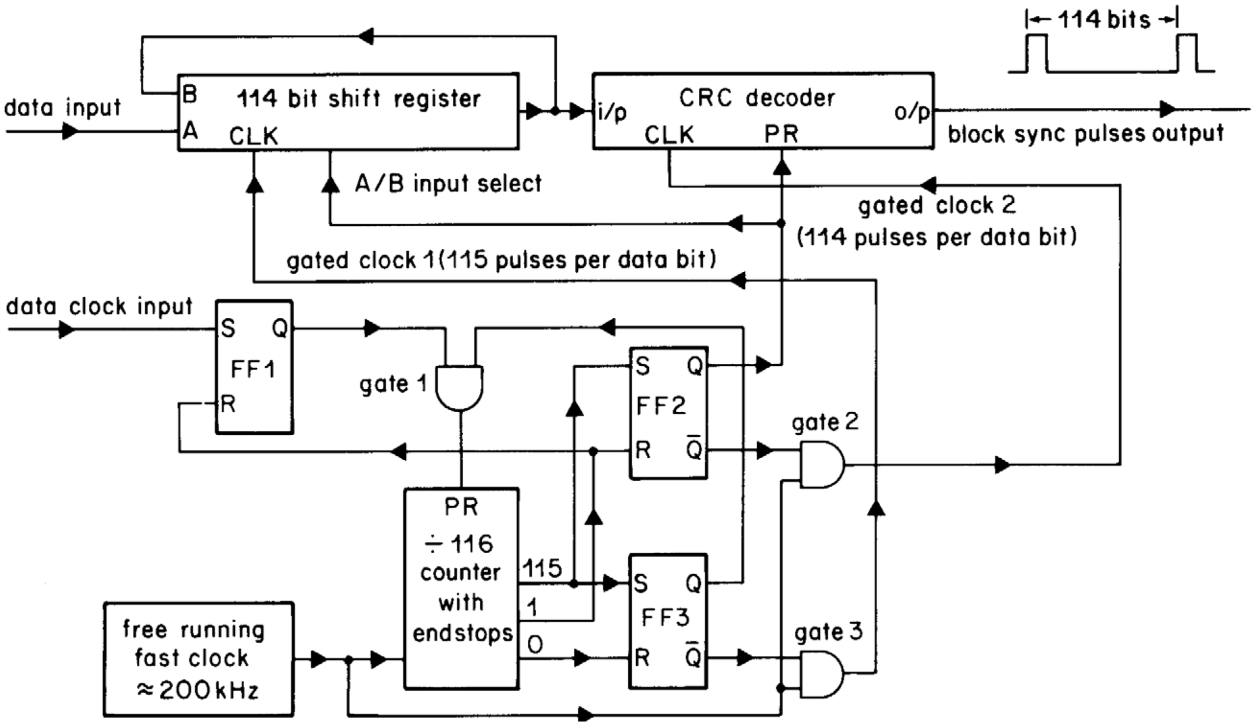


Fig 9 Block synchronisation detection circuit

Assume that the ÷ 116 counter is initially on its top endstop (state 115). Then FF2 and FF3 are set and FF1 is reset. The gated clocks to the 114-bit shift-register and the CRC decoder (gated clocks 1 and 2) are inhibited and the CRC decoder is preset to the 'all-ones' state.

On the next data clock pulse FF1 is set which in turn resets the ÷ 116 counter to state 0. This resets FF3 which enables the fast clock (gated clock 1) to the 114-bit shift-register. This has its A input selected and thus the new

data bit is entered into its left-hand end; the CRC decoder remains preset and not clocked. On the next fast clock pulse (state 1 of the ÷ 116 counter) FF2 resets which enables the fast clock (gated clock 2) to the CRC decoder, removes its preset, and selects the B (recirculating) input of the 114-bit shift-register. FF1 is reset ready for the next data clock-pulse.

Before then, however, the fast clock circulates the 114 bits currently stored in the shift-register around and thus passes them serially into the CRC decoder where the syndrome (i.e. the remainder of the polynomial division) is calculated. If this is zero a block synchronisation pulse is given out by the CRC decoder.

With high probability (99.998%) this will only occur when the stored 114 bits are a complete error-free block (with the transmitted CRC word in the leftmost 16 bits and the block-type address in the rightmost 4 bits of the shift-register). This CRC decoding must all be achieved in under one data bit period (≈ 842 µs) .

On the next data-clock pulse the whole process repeats with the new data bit in the leftmost cell of the 114-bit shift-register and all the other bits shifted along one place to the right. Thus a synchronisation pulse will usually be derived once every 114 bits and will mark the end of each received block.

These block synchronisation pulses cannot, however, be used directly because although with this algorithm false block synchronisation pulses due to data mimicking or errors ill be infrequent they will, on average (with random data) occur once every 2^{16} bits or approximately once per minute. Similarly when errors occur, block synchronisation pulses will be missed because even with correct block synchronisation a non-zero syndrome will not result.

Thus it is necessary to have some sort of block synchronisation flywheel to eliminate spurious synchronisation pulses and fill in the missing ones. This could be achieved with any one of a number of standard strategies, one of which is described below and in the flow-diagram of Fig. 10.

A3-2 Block Synchronisation Flywheel

Suppose that the block synchronisation system has three states (see Fig. 10):

1. Search mode: the system searches for a block synchronisation pulse on every bit-shift of the received data and resets the bit-counter (÷ 114) as soon as one is received. Message data processing is disabled and the display (if any) blanked or set to some predetermined state (e.g. question-marks) until two block synchronisation pulses are found exactly 114 bits apart.

2. Lock mode: as soon as two block synchronisation pulses are found 114 bits apart the system moves to the lock mode. Here message processing is enabled and information for display displayed. The system uses the ÷ 114 counter reset in the search mode as the bit counter and only looks for block synchronisation pulses in the expected positions 114 bits apart. If a block synchronisation pulse is missing (e.g. on first entering the lock mode from the search mode) the system moves to the check mode.

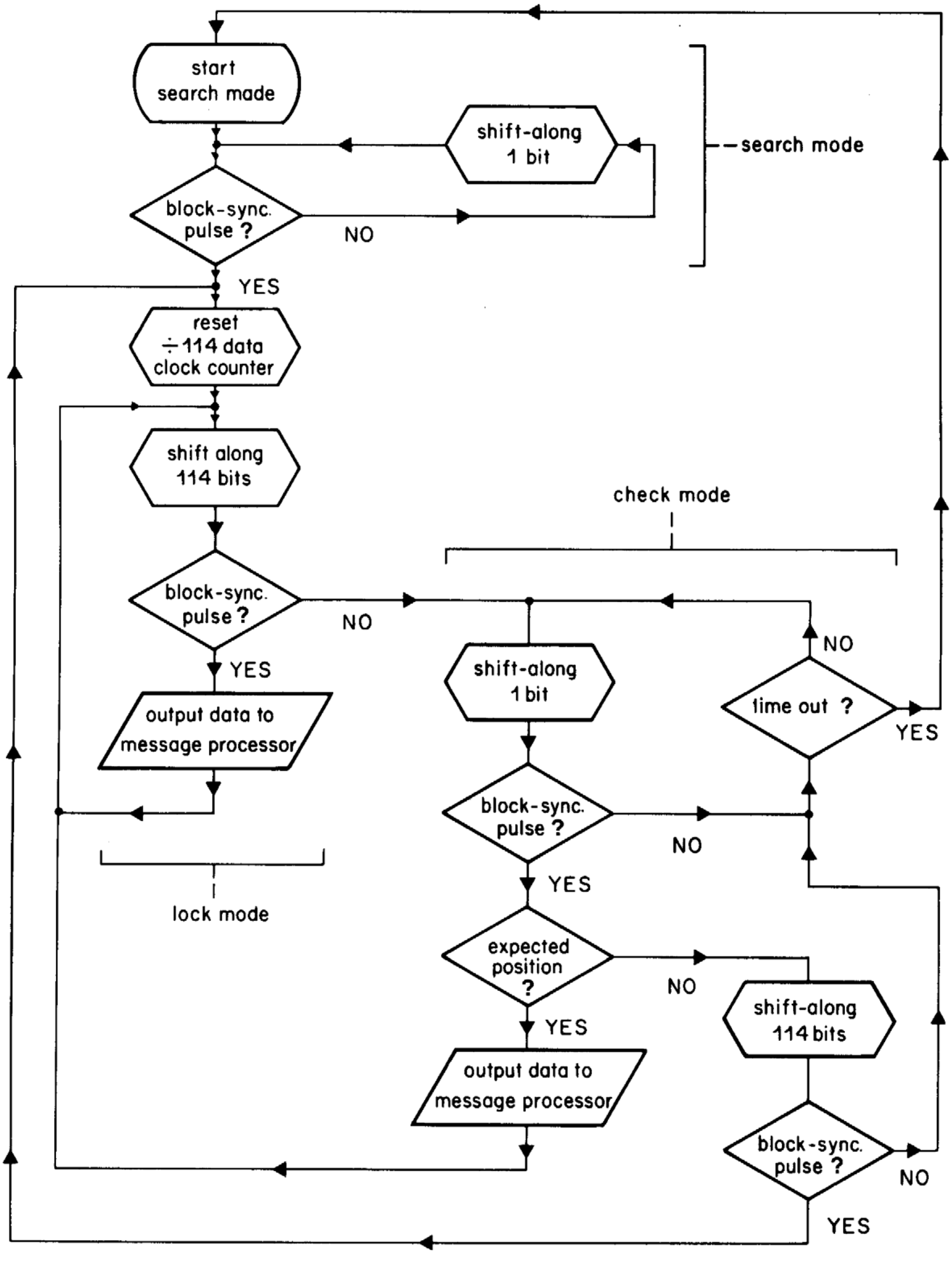


Fig 10 Block synchronisation algorithm

3. Check mode: on entering the check mode the ÷ 114 counter is not reset but the system searches for a block synchronisation pulse on every data clock pulse. If a synchronisation pulse is found in an unexpected position (as indicated by the ÷ 114 counter) the system checks for a further block synchronisation pulse exactly 114 bits later. If this is found the ÷ 114 counter is reset to accept this new synchronisation position and the system re-enters the lock mode.

If a second block synchronisation pulse is not found the system continues to search bit by bit until either a pair of synchronisation pulses 114 bits apart are found or a predetermined time elapses (typically 1.5 seconds) without this condition being satisfied in which case a time-out flag is set and the system moves back to the search mode.

If at any time during the check mode a block synchronisation pulse is found in the expected location (as indicated by the ÷ 114 counter) the system moves directly back to the lock mode.

Thus on switch-on or on tuning to a new station the system starts in the search mode. As soon as 114 valid data bits have been received the block synchronisation checker can start to check for block synchronisation pulses. As soon as a zero remainder results in the CRC decoder and a block synchronisation pulse is issued the ÷ 114 counter is reset. Exactly 114 bits later the system checks for a further block synchronisation pulse. If one is found the system moves to the lock mode and starts to process the message data. If it is missing the system moves to the check mode and either confirms or rejects the selected synchronisation location. Either way the system should rapidly move to the lock mode with the correct block-synchronisation location.

An alternative strategy would be to note the frequency of occurrence of the block synchronisation pulses in all 114 possible locations and select the one with the largest count of synchronisation pulses at any given time.

Appendix IV

Details of the Message Content

to be Transmitted in the Present

BBC BBC Experimental Radio-Data Broadcasts

Three BBC v.h.f./f.m. radio transmitters in the London area are currently carrying the experimental radio-data signals described in this provisional specification. The frequencies of these transmitters are given below:

Network	Frequency
BBC Radio 1/2	89.1 MHz
BBC Radio 4	93.5 MHz
BBC Radio London*	94.9 MHz

Details of the types of message broadcast in the present field-trials are given together with their length and repetition rate in Table 2.

Further details of the contents of the Type 0 blocks (including the CRC words) are given in Table 3.

* *Low-power local radio transmitter*

Table 2 Summary of the Messages in the Radio-data

Message Content	Example	Contained in Block Types	Application Display (D) or Control (C)	Number of Bits	Number of Characters	Repetition Rate (per second)	Remarks
National Code	0 (hex)	All	C	4	-	≈ 10	Basic Information Phrase
Network Code	134 (hex)	All	C	9	-	≈ 10	
Local Area Code	0 (hex)	All	C	3	-	≈ 10	
Programme Type	4 (hex)	All	C	4	-	≈ 10	
Decoder Control	11 (hex)	Type 0	C	5	-	≈ 1	Includes music / speech identifier
Programme Item Number	31 5 14 24 (hex)	Type 0	C	20	-	≈ 1	Week of year, day-of week, hour-of-day minute-of-hour, in binary code.
Network Name	BBC LON.	Type 0	D	49	7	≈ 1	ASCII (ISO 646) Characters sent m.s.b. (b_7) first
Pseudo-random sequence	-	Type 15	None	74 bits of p.r.b.s. in a block			Sequence length = 63 bits

Table 3

<u>Details of the Contents of Type 0 Blocks in the present Radio-data field-trials</u>

Network	National Code	Network Code	Local Area Code	Programme Type	Decoder Control	Programme Item Number Week Day Hour Minute	Network Name	CRC Word
BBC Radio 1/2 (89.1 MHz)	0	132	0	4	11	11 3 OA 00	10A1434149920 (BBC▲ R2▲ in ASCII)	E934
BBC Radio 4 (93.5 MHz)	0	134	0	1	00	11 3 OB IE	10A1434149A20 (BBC▲ R4▲ in ASCII)	ODEA
BBC Radio London (94.9 MHz)	0	135	0	6	11	11 3 OB 2D	10A1434A327CE (BBC▲ LON in ASCII)	44D9

Notes:

1) All the messages in this table are expressed in hexadecimal code (with the most significant zeroes (left-most) suppressed to give the correct length for each item).

   Thus the Network Code for Radio 2 is 132 = 100110010 in binary (the leading zeroes are suppressed to give the correct length of 9 bits). The m.s.b. (i.e. the left-most digit) is transmitted first.

2) Week 11 day 3 Hour OB Minute lE translates as 11-30 hrs. (UTC) on Wednesday in Week 17.

   For 1981 this would be 22nd April.

3) ▲ indicates the ASCII 'space' character.